

## L O R D ' S A D D I T I V E S L L C

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## FACSIMILE TRANSMITTAL SHEET

TO:	FROM:
Matthew Daniels	Stephen Bales
COMPANY:	DATE:
USPTO	5/5/2008
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Mr. Daniels,

We would appreciate an interview to discuss the following responses to the Office Action rejections of April 9, 2008.

We propose to add Independent claim 17 and dependent claims 18 and 19. [No changes have been made to the other claims all of which are shown in the Appendix].

17. (New) In the method for forming composite products consisting of a thermoplastic material, a lignocellulosic material, and at least one of the group consisting of a lubricant, a cross-linking agent, a UV stabilizer, an inhibitor, and a coupling agent such as to increase their resistance to surface visual impairment caused by mold attack, the improvement which consists of incorporating an amount of a boron-containing fungicide selected from the group of synthetic calcium borate, colemanite, ulexite, or mixtures thereof in the range of from about 2 to 12 percent by weight of said composite product prior to forming said composite product.
18. (New) The method according to claim 17 where the boron-containing fungicide is zinc borate.
19. (New) The method according to claim 17 where the boron-containing fungicide is boric acid.

Claim 17 narrows Claim 16 by eliminating boric acid, zinc borate and the foaming agent, thereby removing rejections based on Chow (boric acid), Pelikan (foaming agent), and Borogard (zinc borate). This removes all the rejection elements noted in the OA #'s 2, 6, & 7 regarding Claim 16.

Claim 18 removes Chow and Pelikan, while Claim 19 removes Pelikan and Borogard.

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The following is a draft of our arguments to the OA Rejected Claims.

### **OA 2 Rejected Claims 1, 3-5, 10, and 16**

1. Chow's boric acid limits are 0.02% - 20% (2:38-45) of the lignocellulosic material which is itself 10 – 60% of the weight of the composite. This gives a range of 0.002 – 12% of the total composite range which is greater than the 2–12% of the present invention's claim 1.

Further, Chow' preferred limits, which would compare to the 3 – 5% range of the current invention, are 0.9 – 1.5% of the lignocellulosic material. This would translate to 0.09 – 0.9%. This is well outside the 3 – 5% range.

2. The color darkening and odor occur only if the composite is produced at temperatures above 200 °C and are the result of the lignocellulosic degradation created at these temperatures (1:25-41). These results occur immediately following production where the color darkening noted in the present invention is the result of mold formation and occurs only after months of exposure to the elements. As a result, one following Chow's method would be experimenting and optimizing on the wrong result and would not achieve the results and benefits of the current invention.

Chow's Examples illustrate how this would occur. Example I (5:10-42) contrasts a sample with no boric acid with one containing only 0.8% at processing temperatures of 200 °C or less. As expected, there was no discoloration of the lignocellulosic material and color of both sample was the same. However the odor of the 0.8% sample was less, leaving one using Chow to conclude that 0.8% was an effective loading—a much lower loading than the minimum value of 2% in the present invention.

Example IV (6:37-7-30) contrasts boric acid samples from 1% to 20% at processing temperatures of 220 and 250 °C. Table I and the commentary illustrate the inability to correlate the boric acid content with color change caused by temperature degradation. Increased content was found to decrease color darkening at all press times at the 250 °C level but at the 220°C level just the opposite occurred. Further, per Table I, boric acid concentration of 1% gave a similar color result as the 20% sample. In the present invention there was a positive dose-response correlation.

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**OA 4: Rejected Claims 1, 3-6, 8-12, and 14**  
**OA 9: Rational to reject Unexpected Results**

1. OA 4 at p4: "Aida lacks sufficient specificity to anticipate the claimed range" and therefore the rejection relies on obviousness.

Applicant submits arguments presented on 3-20-2008 regarding unexpected results and the additional arguments presented on this page transverse the obviousness rejection.

2. OA 4 at p5: As to Claim 10, Lloyd teaches that Borates such as boric acid ... (1:32-36).

Applicant notes that Lloyd then states that boric acid is soluble in water which, when used in composites, results in poor mechanical strength (1:37-42).

3. OA 9 at p 10, 11

Items a & b. The Borogard ZB reference is July 26, 1993—this will be stated for the record.

The Borogard ZB label is instrumental in demonstrating why the use of zinc borate in WPC's to reduce mold was a surprising result. Although the label states that zinc borate could be used to control mold fungi such as *Aspergillus Niger* at 3-30phr, the chemical proved to be ineffective at that task as shown in the prior art of Marks and Ross.

Marks (USPN 6,416,789 at 1:24-35) states "zinc borate ...does not provide good protection against mold, mildew and staining fungi at typical use levels. Ross makes a similar statement. The only typical use levels were contained in the EPA Registered Borogard ZB label, which was the only legally registered zinc borate that could have been used as a fungicide at that time. It can not be ignored that two people skilled in the art found this product ineffective in plastics.

The Borogard ZB label does not claim mold fungi effectiveness in wood composites. The fungi listed in the label, *Trametes versicolor* and *Gleophyllum trabeum*, are decay (rot) fungi.

Given that zinc borate was ineffective in plastics and not even claimed to be effective in wood (which because it is a food for mold fungi is more susceptible to mold than plastic), it is surprising that (1) the chemical was found to work at all in wood plastics and (2) that it works only after adding at least 2%.

Item c. Other than the present invention, Laks was the first to recognize the effectiveness of zinc borate as an effective mold suppression chemical in WPC's.

Item d. Applicant's assertion is colemanite does not effectively suppress mold growth. Touval only shows that colemanite, if combined with stannic oxide, can work as a fire retardant in PVC.

Item e. No further comments other than –the March 20<sup>th</sup> submission

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**OA 5 Rejected Claims 1, 3-5, 6, 8, 9, 11, and 15**

1. Touval teaches that non-halogenated polyethylene requires a range of 4- 25 % of flame retardants. He then demonstrates in Example 3 (8:66 – 9:4) that colemanite is even less effective than the lower portion of this range. Even when the polyethylene is augmented with a halogen( 8% chlorinated paraffin) and 2% stannic oxide is added, at least 8% colemanite is required (Table 2). Eight percent is well out of the range of the current invention's Claim 3 and in the portion end of Claim 1..
2. Pelikan uses a lignocellulosic material as a carrier for a gas foaming medium of either water or an aqueous dispersion. Pelikan teaches a range of 3.5 - 23% lignocellulosic material as he requires the carrier plus medium to be 5 – 25% of the plastic and the medium to be 8 to 30% of the carrier (6:40-52). As a result the plastic is > 75% of the composite, while the plastic range in the current invention is 25 – 75%.
3. Pelikan teaches a lignocellulosic minimum particle size of 350 microns in diameter and 1-8 mm in length (6:39-42). Clemons (UDSA) in *Wood Plastic Composites in the US*" identifies the typical wood particle size as 10 to 80 microns. Verhey in *Wood Particle Size Affects the Decay Resistance of Woodfiber-Thermoplastic Composites*, identifies that a wood plastic composite becomes more vulnerable to decay as particle size increases. Verhay's worst case is a 20 mesh particle which is only .84 mm.

Pelikan's primary function for a lignocellulosic material is as a carrier for a foaming agent. Given he teaches a relatively small (<25%) lignocellulosic content, a 1-8mm particle size may be acceptable. But for the composites described in the current invention, such large particles are unacceptable as they would give an unacceptable vulnerability to decay.

4. The addition of lignocellulosic material would provide an unacceptable component to Touval's invention of a flame retardant composite containing Stannic Oxide. Holmes (USDA/FPL) in *Effect of Fire-Retardant Treatments on Performance Properties of Wood* identifies that Stannic Oxide stimulates glowing of burning wood. Glowing is the visual evidence of combustion of the carbon in the char layer of the burning wood. Wood that has been effectively treated should not exhibit any after-glow.

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**OA 6 Rejected Claims 1, 3-6, 8-12, 15, and 16**

1. Applicant's OA 4 arguments regarding unexpected results and OA 5 arguments regarding Pelikan apply to OA6.
2. Applicant's OA 9 arguments regarding Borogard apply to OA6.

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## Appendix A Claims

1. (Previously Amended) In the method for forming lignocellulosic thermoplastic composite products such as to increase their resistance to surface visual impairment caused by mold attack, the improvement which comprises incorporating an amount of a boron-containing fungicide in the range of from about 2 to 12 percent by weight of said composite product prior to forming said composite product.
2. (Canceled)
3. (Original) The method according to claim 1 in which said amount of boron-containing fungicide is in the range of from about 3 to about 5 percent by weight of said composite.
4. (Original) The method according to claim 1 in which said lignocellulosic material is selected from the group consisting of wood, ground rice hulls, kenaf, jute, and coconut shells.
5. (Original) The method according to claim 1 in which said thermoplastic material is selected from the group consisting of polyethylene, high-density polyethylene, polystyrene, and polyvinyl chloride.
6. (Original) The method according to claim 1 in which said boron-containing fungicide is calcium borate.
7. (Canceled)
8. (Original) The method according to claim 6 in which said calcium borate is a naturally occurring borate.

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9. (Currently Amended) The method according to claim 8 in which said calcium borate is selected from the group consisting of ulexite and colemanite.
10. (Previously Amended) The method according to claim 1 in which said boron-containing fungicide is boric acid.
11. (Previously Amended) The method according to claim 1 in which said boron-containing fungicide is selected from a group consisting of zinc borate, calcium borate, boric acid, or mixtures thereof.
12. (Previously Amended) The method according to claim 8 in which said calcium borate is colemanite.
13. (Canceled)
14. (Previously Amended) The method according to claim 1 in which said boron-containing fungicide is zinc borate.
15. (Previously Amended) The method according to claim 1 in which said thermoplastic material is polyvinyl chloride.
16. (Previously Submitted) In the method for forming composite products consisting of a thermoplastic material, a lignocellulosic material, and at least one of the group consisting of a lubricant, a cross-linking agent, a UV stabilizer, a blowing agent, an inhibitor, and a coupling agent such as to increase their resistance to surface visual impairment caused by mold attack, the improvement which consists of incorporating an amount of a boron-containing fungicide selected from the group of zinc borate, synthetic calcium borate, colemanite, ulexite, boric acid, or mixtures thereof in the range of from about 2 to 12 percent by weight of said composite product prior to

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forming said composite product.

17. (New) In the method for forming composite products consisting of a thermoplastic material, a lignocellulosic material, and at least one of the group consisting of a lubricant, a cross-linking agent, a UV stabilizer, an inhibitor, and a coupling agent such as to increase their resistance to surface visual impairment caused by mold attack, the improvement which consists of incorporating an amount of a boron-containing fungicide selected from the group of synthetic calcium borate, colemanite, ulexite, or mixtures thereof in the range of from about 2 to 12 percent by weight of said composite product prior to forming said composite product.

18. (New) The method according to claim 17 where the boron-containing fungicide is zinc borate.

19. (New) The method according to claim 17 where the boron-containing fungicide is boric acid.

**FOREST PRODUCTS LABORATORY (Madison, Wis. 53705)  
FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE  
Approved Technical Article**

# 6

## **Effect of Fire-Retardant Treatments on Performance Properties of Wood**

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The one million fires in buildings in the United States account for about two-thirds of the 12,000 people who die each year in fires. The property loss in building fires is about 85 percent of the total annual \$3 billion property loss in fires (1). Building contents are often a primary source of fire and are usually responsible for fire-related deaths before structural members become involved. Nevertheless, wood and wood-base products, extensively used both as structural members and as interior finish in housing and buildings, can be contributors to fire destruction.

To reduce the contribution of wood to fire losses, much research through the years has gone into development of fire-retardant treatments for wood. A total of 21.3 million pounds of fire-retardant chemicals were reported used in 1974 to treat 5.7 million cubic feet of wood products (2). The amount of wood treated was about one tenth of 1 percent of the total domestic production of lumber and plywood and has increased ninefold in 20 years.

How does our research stand in rendering wood fire retardant? What is the effect of fire-retardant treatments on the fire performance properties of wood and on the physical and mechanical properties of wood that are important to its utility? Discussion will be limited to fire retardancy obtained by pressure impregnation, which is currently the most effective method. Fire-retardant coatings, wood-plastic combinations, and chemical modifications of wood will not be considered.

### Fire-Retardant Chemicals

Past research on fire retardants, including those for wood; from about 1900 to 1968 is reviewed in John W. Lyons' comprehensive reference book, "The Chemistry and Uses of Fire Retardants" (3). A more recent review by Goldstein (4) gives additional information on fire-retardant chemicals and treatment systems for wood and also discusses some of the topics of this

82 In Chapter 6: "WOOD TECHNOLOGY: CHEMICAL ASPECTS," 1977  
Irving S. Goldstein, ed. ACS Symposium Series 43.  
American Chemical Society, Washington, D.C.

6. HOLMES *Fire-Retardant Treatment*

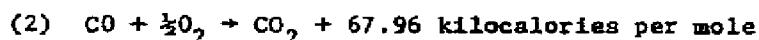
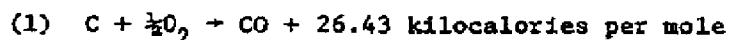
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prevent flaming combustion of the wood and prevent spread of fire over the surface. Wood, properly treated, will be self-extinguishing of both flaming and glowing once the primary source of heat and fire is removed or exhausted.

### Glowing

Glowing is the visual evidence of combustion of the carbon in the char layer of the burning wood. If flaming of the released combustible gases has ceased, the glowing of the char is usually termed afterglow.

Of the several possible oxidation reactions in glowing combustion, both Browne (5) and Lyons (3) in their reviews show one possibility to be a two-stage reaction:



The first reaction occurs on the surface of the char and the second is a gas-phase reaction.

Wood that has been effectively treated should not exhibit any afterglowing. Reviews (3,5) covering the subject of glowing point out that the mechanism involved in glow retardance is not clear. Both physical and chemical theories have been suggested. Physical methods include the exclusion of oxygen from the carbonaceous char by formation of coatings of the fire retardant during the combustion process or by a cooling effect due to the fire retardant. The chemical theory with the most supporting evidence indicates that effective glow retardance increases the ratio of CO to CO<sub>2</sub>.

If the reaction can be directed mostly to the monoxide, step (1) above, the heat liberated is only 28 percent of that given off when the reaction continues to the dioxide. Thus glowing may be eliminated by an insufficient amount of heat to continue combustion.

Effective glow retardants for wood are the ammonium phosphates, ammonium borates, boric acid, phosphoric acid, and compounds that yield phosphoric acid during pyrolysis (3,5). Some chemicals that are reported to stimulate glowing are chromates, molybdates, halides of chromium, manganese, cobalt and copper, and ferric and stannic oxides (5,10). Chemicals found to be ineffective in retarding afterglow in a limited study were ammonium sulfate and sodium borates (10).

### Combustion Products

The combustion products of burning wood--smoke and gases--are becoming of increased importance. Code and building officials, builders, producers of building materials and furnishings, and all

# WOOD PARTICLE SIZE AFFECTS THE DECAY RESISTANCE OF WOODFIBER/ THERMOPLASTIC COMPOSITES

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PETER E. LAKS<sup>\*</sup>

## ABSTRACT

The fungal durability of woodfiber/thermoplastic composites is an area of recent scientific interest. Model composites containing 50 percent wood, on an oven-dry composite weight basis, were produced using a range of wood particle sizes from two different wood species. The decay resistance of the composites was evaluated against *Gloeophyllum trabeum* and *Trametes versicolor*. It was found that weight loss increased as the wood particle size increased. Decay in the pine-based composites was more sensitive to particle size than the maple-based composites. More wood volume is accessible to the fungi on the faces and along the edges of composites produced with large particles, resulting in higher weight losses. In addition to the exposure of greater wood volume when large particles are used, forces induced by moisture absorption and swelling may act to increase the accessibility of the wood in these composites.

Recent work on the fungal durability of woodfiber/thermoplastic composites (WPCs) has shown that these materials have substantial inherent decay resistance. However, exposure to harsh environmental conditions can result in decay. A report of basidiomycete and soft-rot fungal growth on a WPC boardwalk in Everglades National Park in Florida (Morris and Cooper 1998) appears to have alerted the industry and the scientific community to a potential problem. Fundamental information relating to the decay susceptibility of WPCs is becoming available. Patterns of fungal colonization of WPCs have been investigated (Mankowski and Mortell 2000) along with the effects of wood loading and preservative content on decay susceptibility (Simonsen et al. 2002, Verhey et al. 2002, Verhey et al. 2001). In addition, the effect of decay on the mechanical properties and creep resistance of

WPCs has been investigated (Silva et al. 2002). This technical note addresses how wood particle size affects the decay susceptibility of WPCs.

## EXPERIMENTAL MANUFACTURING THE COMPOSITES

The composites for this work were produced from either ponderosa pine (*Pinus ponderosa* Dougl. Ex Laws) or maple (*Acer* spp.) furnish (American Wood Fibers, Schofield, Wisconsin) and powdered polypropylene (Exxon PP3505G-E1). All of the composites

contained 50 percent (by weight of the finished panel) dry wood and 50 percent plastic. Wood particle sizes were 20, 40, 60, 80, 100, 140, or 200 mesh for the maple composites and 20, 40, 60, 80, 100, 120, or 140 mesh for the pine composites. All of the furnish types were oven-dried at 103°C for 24 hours prior to incorporation into the composites.

The wood fibers were blended with plastic in a Papenmeier high-intensity mixer for 5 minutes to produce a homogeneous blend. A rectangular mold, with internal dimensions measuring approximately 254 by 406 by 6 mm, was filled with the blended wood and plastic mixture and placed in a laboratory scale hot-press with 450- by 450-mm-square platens. The press was closed until the heated platens just contacted the top mold plate; no measured pressure was applied. The mixture was allowed to heat under these conditions for 5 minutes prior to pressing at 72.5 mPa of pressure (7 min. and 200°C). Following hot-pressing, the mold was transferred to a cold-press where the panel was allowed to cool to approximately 50°C under 72.5 mPa of pressure. The final

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The authors are, respectively, PhD Candidate and Professor, School of Forestry and Wood Products, Michigan Technological Univ., 1400 Townsend Dr., Houghton, MI 49931. The authors would like to thank Exxon Chemical Americas and American Wood Fibers for donations of materials that were used in this work. In addition, we would like to thank Dana Richter and Amy Stephens for assistance with the fungal testing. This paper was received for publication in October 2001. Reprint No. 9381.

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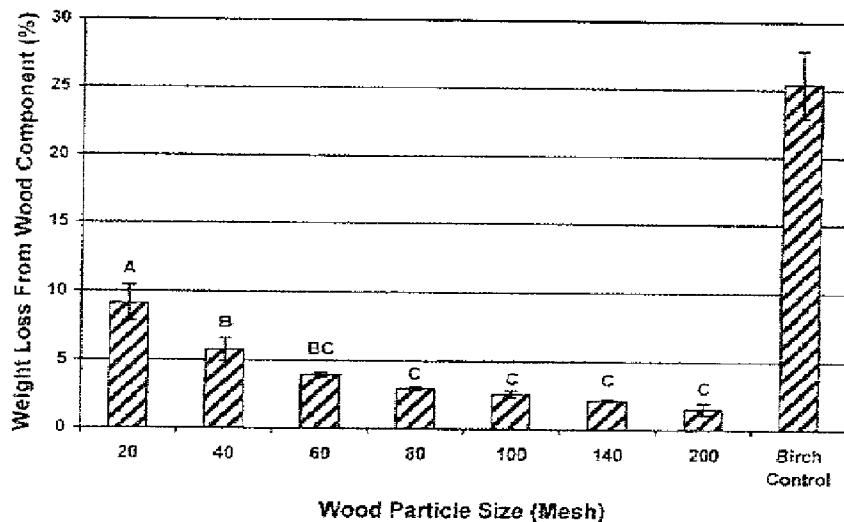


Figure 1.— Mean weight loss from the maple composites (*Acerspp.*) after exposure to *Trametes versicolor*. The error bars span one standard deviation of the five individual data points and the letters above each column represent the Tukey group for each of the individual means. Means with the same letter designation are not significantly different at a family error rate of 0.05 for all of the comparisons. Paperbirch (*B. papyrifera*) was the solid wood control.

step in the manufacturing process was to allow the panels to cool to room temperature under pressure from a block of aluminum on a concrete floor. This final cooling step prevented the panels from warping as they cooled to room temperature. The flat panels were trimmed to final dimensions of 230 by 380 mm.

#### SOIL-BLOCK TESTING

Laboratory exposures to fungal monocultures were used to evaluate the fungal resistance of the model composites. Decay was quantified through the measurement of weight loss. A standard procedure, AWPA E10-91 (AWPA 2000), was followed as a guideline for the test. The only modifications that were made to the standard procedure were that the brown-rot samples were introduced into the jars at the same time that the feeder strip was inoculated and that the blocks were a non-standard size. These modifications have been previously discussed (Verhey et al. 2001). It was not possible to use the standard 19-mm (3/4 in.) cubic samples because the panels were nominally 6 mm (1/4 in.) thick. Square samples measuring 25.4 by 25.4 mm (1 in. squares) were cut from the composite panels for the decay test. The thickness of the samples was

simply the thickness of the individual panels.

Weight loss from the composites was converted to weight loss from the wood component. Previous work has shown that no weight loss results from exposing pure plastic to the brown-rot fungus under the same experimental conditions (Verhey and Laks 2000). Since it is not likely that any weight loss was due to degradation of the plastic, all weight loss was assumed to be from degradation of the wood component. Therefore, for these 50 percent wood composites, the percent weight loss in terms of the wood component was double the overall weight loss from the composite.

A detailed summary of the test procedure was reported in our previous work on these types of composites (Verhey et al. 2001). Two species of fungi that produce different types of decay were used to evaluate the durability of the composites. Brown-rot fungi are only capable of metabolizing the polysaccharide components of the wood, while white-rot fungi can degrade both the polysaccharide and lignin components. The brown-rot fungus, *Gloeophyllum trabeum* (ATCC 11539, [Fr.] Murr.), and the white-rot fungus, *Trametes versicolor* (MAD 697, [Lz Fr.] Pilar).

were used in this study. Solid wood controls were also included to verify that the fungus was capable of decaying untreated wood. Paper birch (*Betula papyrifera*, Marsh.) was used with *T. versicolor* and southern yellow pine (*Pinus spp.*) was used with *G. trabeum*.

#### DATA ANALYSIS

MINITAB™ (Release 13.1) was used to perform Tukey's multiple comparisons tests (family error rate = 0.05) on the weight loss results for each of the three soil-block exposures. Tukey's test is conservative (has a lower type I error rate) when compared to other means separations tests such as Duncans's multiple-range test or the Newman-Keuls test and therefore has lower power, but it handles unequal numbers of means in each group well (Frenad and Wilson 1997, Montgomery 1997). Tukey's comparison test also guarantees a specified experiment-wise significance level whereas other statistical comparison methods can compromise the overall significance level to increase power. When comparing means from soil-block tests, it is quite likely that unequal numbers of means will be encountered due to the contamination of some jars, so the use of Tukey's test may be warranted.

#### RESULTS AND DISCUSSION

##### WHITE-ROT DECAY RESULTS

White-rot fungi are known to produce the largest weight losses in angiosperm woods. Verhey et al. have shown that *T. versicolor* failed to produce much decay in all but the highest wood loading composites that contained coniferous wood furnish (Verhey et al 2001). Conversely, the brown-rot fungi produced measurable decay in all of the composites that were tested. In the work reported here, white-rot exposure was only carried out against the maple furnish composites.

The *T. versicolor* experimental results (Fig. 1) show reasonably good fungal viability, as demonstrated by the 25 percent weight loss from the paper birch control samples. Weight losses from the wood component of the maple composites were relatively low, with a maximum of approximately 9 percent loss from the 20-mesh composite. Reducing the particle size to 60-mesh size produced a statistically significant reduction in weight loss. Beyond 60-mesh particle size, weight loss dropped to low levels and the differences were not sta-

tistically significant although a continually decreasing trend is apparent in the means.

#### BROWN-ROT DECAY RESULTS

The southern yellow pine, solid wood control samples for the brown-rot test lost an average of 44.6 percent of their mass during incubation (Figs. 2 and 3). The overall brown-rot weight losses from the maple composites, for particle size 80-mesh and larger, were almost double those produced by the white-rot fungus (Fig. 2). Statistically significant reductions in decay levels corresponded with the reduction of particle size until a low level of decay was reached. This trend is identical to that which was observed for white-rot decay of the same maple furnish composites.

Decay in the ponderosa pine composites appeared to be more sensitive to the first particle size reduction than the maple composites. This is apparent upon comparing the brown-rot test results for both types of composites. Approximately 18 percent wood weight loss (Figs. 2 and 3) was observed in each of the 20-mesh composites, but a reduction of the pine particle size to 40-mesh produced a larger change in the pine composites. No further significant decrease in weight loss was observed by reducing the particle size in the pine composites, while further reduction of the particle size in the maple composites continued to result in statistically significant changes.

#### DISCUSSION

In general, the results of all three fungal exposure tests show that composites produced from blends of large particles and plastic are more susceptible to fungal decay than composites produced with small wood particles. In these model composites, protection from fungal decay will be achieved only by the encapsulation of wood particles in a continuous plastic phase because no chemical preservative has been incorporated into the system. The wood particles that are exposed on the surface of the composite and on the cut edges will undoubtedly be susceptible to decay. Ideally, once the wood on the surfaces has been decayed, the fungus will be prevented from contacting any more wood by the plastic phase and weight loss will be limited.

If weight loss from our composites was due only to the decay of wood parti-

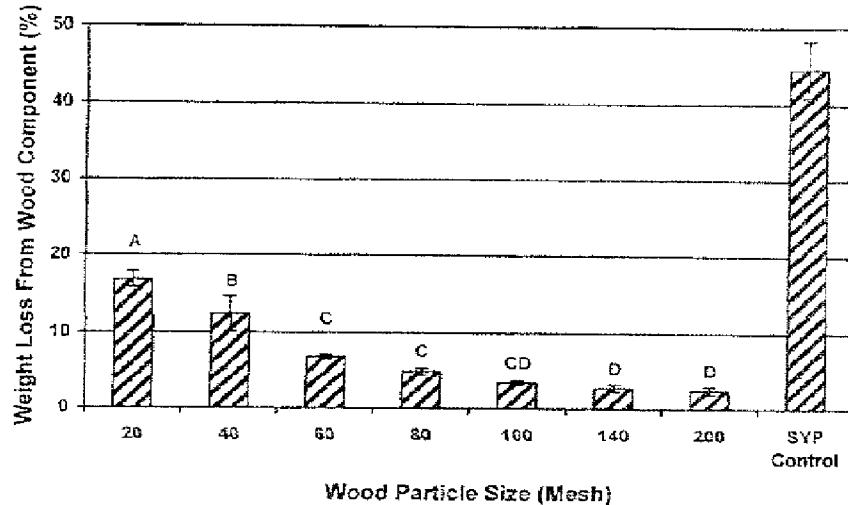


Figure 2.—Mean weight loss from the maple composites (*Acerspp.*) after exposure to *Gloeophyllum trabeum*. The error bars span one standard deviation of the five individual data points and the letters above each column represent the Tukey group for each of the individual means. Means with the same letter designation are not significantly different at a family error rate of 0.05 for all of the comparisons. Southern yellow pine (*Pinus spp.*) was the solid wood control.

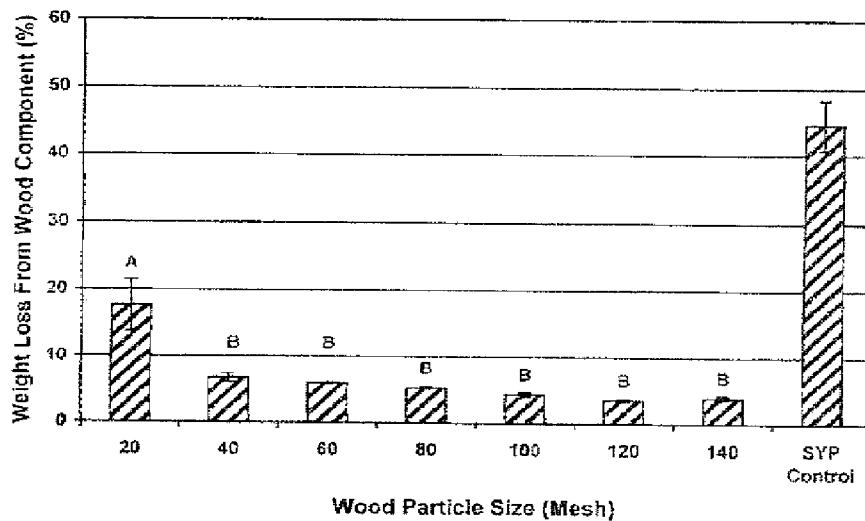


Figure 3.—Mean weight loss from the ponderosa pine (*Pinus ponderosa*) composites after exposure to *Gloeophyllum trabeum*. The error bars span one standard deviation of the five individual data points and the letters above each column represent the Tukey group for each of the individual means. Means with the same letter designation are not significantly different at a family error rate of 0.05 for all of the comparisons. Southern yellow pine (*Pinus spp.*) was the solid wood control.

cles that were exposed at the surfaces and on the cut edges, then the composites that contained larger wood particles would be expected to show greater weight losses than composites produced from smaller wood particles. This is be-

cause fungal contact with any part of a large wood particle, even if only a small portion of that particle were exposed, would still leave the whole particle subject to decay. Composites produced with smaller wood particles will have more

wood surface area that will be exposed on the composite surfaces, but the bulk of the wood volume in the composite is protected from decay by encapsulation. The effect of exposing more wood volume (through many fewer particles) to decay could explain the higher weight losses from the 20-mesh composites.

In addition to the effect of large particles leading to higher weight losses because less volume is protected by the plastic phase, the composites show signs of thickness swell upon exposure to moisture. Swelling of the particles on the edges and surfaces of the blocks could lead to interface failure between the wood and plastic particles and also within the plastic phase. This could expose progressively more interior wood particles to the decay fungus. Although we did not measure the thickness swell of these blocks, the composites that contain large wood particles can be expected to experience greater thickness swelling than composites that contain small wood particles because of their comparatively large continuous volume. The large internal forces that are generated as the wood swells may overcome the tensile strength of the plastic and lead to rupture. Small voids in the plastic phase, created as a result of thickness swelling, can act as passageways that the fungal hyphae can propagate into. This pattern of attack has been previously observed (Mankowski and Morrell 2000). Propagation of the fungus into the interior of the composite through swelling-induced defects can lead to further contact with wood particles and more subsequent decay. The lack of a coupling agent to facilitate bonding between the non-polar plastic and polar wood phases may further increase the decay susceptibility of the particles by reducing the efficiency of encapsulation.

#### CONCLUSIONS

Particle size of the wood component has an effect on the inherent decay resis-

tance of WPCs. The results of all three fungal tests show clearly that a reduction of particle size from 20 to 40 mesh produces a significant reduction in the decay susceptibility of the model composites using this laboratory decay procedure. Fungal decay susceptibility increases with particle sizes greater than 60 mesh for maple and 40 mesh for pine furnish. Weight loss in the pine furnish composites was more sensitive to the effects of the initial particle size reduction, but less sensitive to further reductions than the maple composites. The use of small wood particles appears to result in more effective encapsulation of the wood volume in the composite and provides better preservation. Decay of exposed wood, primarily at the surfaces of the test specimens, results in lower weight losses for composites produced with small wood particles. Greater thickness swelling in the composites that contain larger wood particles is also suspected of contributing to decay susceptibility. Our present data do not allow us to attempt to establish the relative significance of each effect on the decay susceptibility of these model composites.

When designing a commercial composite, the effect of particle size should be considered. The use of relatively large particles (with a high fiber aspect ratio) might improve the mechanical properties of a composite, but the incorporation of a preservative should be considered if it will be used in an application where biological resistance is important. A possible negative synergistic interaction between particle size and wood content may also be important to consider when designing such composites, because our previous work has shown a dramatic increase in decay susceptibility of these model composites when the wood content is increased from 50 to 60 percent (Verhey et al. 2001).

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**P&P Statement:** The use of larger wood particles in woodfiber/thermoplastic composites increases their susceptibility to fungal decay. This may be of particular interest to those who may try to use large wood particles in an attempt to improve the strength or creep resistance of these composites.